



DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER
DIVISION NEWPORT
OFFICE OF COUNSEL (PATENTS)
1176 HOWELL STREET
BUILDING 112T, CODE 00OC
NEWPORT, RHODE ISLAND 02841-1708

PHONE: 401 832-4736
DSN: 432-4736

FAX: 401 832-1231
DSN: 432-1231



Attorney Docket No. 84866
Date: 3 November 2006

The below identified patent application is available for licensing. Requests for information should be addressed to:

PATENT COUNSEL
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 00OC, BLDG. 112T
NEWPORT, RI 02841

Serial Number 11/070,399

Filing Date 25 February 2005

Inventor Kim C. Benjamin

If you have any questions please contact James M. Kasischke, Supervisory Patent Counsel, at 401-832-4230.

20061109073

DISTRIBUTION STATEMENT
Approved for Public Release
Distribution is unlimited

1 Attorney Docket No. 84866

2

3 LOW VOLTAGE PIEZOELECTRIC COMPOSITE FOR TRANSDUCER APPLICATIONS

4

5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 governmental purposes without the payment of any royalties
9 thereon or therefor.

10

11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 This invention generally relates to an acoustic transducer's
14 electromechanical substrate.

15 More particularly, the invention relates to a piezoelectric
16 polymer composite substrate enabling an array of transducers
17 capable of being used with lower voltage than prior art
18 transducers.

19 (2) Description of the Prior Art

20 Several underwater sonar applications exist for high
21 intensity steered directional acoustic beams. A major drawback
22 for piezocomposite constructs is the relatively high drive
23 voltages required to attain significant acoustic intensity per
24 unit area. This is due to the material's intrinsic broadband
25 characteristics and the fact that typical designs operate below

1 resonance where the impedance phase angle is stable. Phase
2 stability is required for broadband waveform generation and
3 reception. The disadvantage of operating off resonance is that
4 higher voltages are required to produce the equivalent acoustic
5 intensity.

6 United States Patent Nos. 4,227,111 and 4,412,148 refer to
7 piezoelectric polymer composite substrates that can be used to
8 construct broadband transducers and arrays for sonar
9 applications. The segmentation of the piezoelectric phase and
10 the decoupling characteristics of the backfill polymer enable
11 large transducer apertures operating in a pure thickness mode of
12 vibration.

13 An electrostriction transducer having intermediate
14 electrodes is shown in Sato et al., United States Patent No.
15 4,633,120. The active layer of the transducer is either lead
16 zirconium-titanate or lead magnesium-niobate. This material is
17 incorporated in a polymer slurry which is applied to a substrate
18 such as a Mylar(t) film. A several hundred micron thick active
19 layer is provided. Conductors such as wires are joined directly
20 to contacts positioned between different active layers. The
21 resulting transducer is provided for use in a print head. No
22 provision is made for joining a massive number of co-fired multi-
23 layered structures in a piezoelectric polymer composite
24 substrate.

1 It should be understood that the present invention would in
2 fact enhance the functionality of the above patent by providing
3 an active substrate consisting of piezoelectric columns within a
4 polymer composite capable of operating at lower voltages.

5
6 SUMMARY OF THE INVENTION

7 In accordance with one aspect of this invention, there is
8 provided a piezoelectric substrate having three or more odd
9 numbers of stacked piezoelectric regions that could be used to
10 construct an array of transducers. Upper and lower contacts are
11 disposed on the end of a stack of piezoelectric regions and
12 intermediate contacts are disposed between the regions. The
13 upper contact is electrically joined by a first trace to a first
14 intermediate contact between the second and third piezoelectric
15 regions. The lower contact is electrically joined by a second
16 trace to a second intermediate contact between the first and
17 second piezoelectric regions. Insulating material is positioned
18 between the first and second trace and the piezoelectric regions.
19 The upper and lower contacts are disposed over the ends of a
20 plurality of piezoelectric stacks or the upper and lower contacts
21 can be segmented for individually addressing the stacks. The
22 insulating material insulates piezoelectric columns from each
23 other.

1 BRIEF DESCRIPTION OF THE DRAWINGS

2 The appended claims particularly point out and distinctly
3 claim the subject matter of this invention. The various objects,
4 advantages and novel features of this invention will be more
5 fully apparent from a reading of the following detailed
6 description in conjunction with the accompanying drawings in
7 which like reference numerals refer to like parts, and in which:

8 FIG. 1 is a top view of a single piezoelectric ceramic rod;

9 FIG. 1A is a cross sectional view of the piezoelectric
10 ceramic rod of FIG. 1 taken along section line A-A;

11 FIG. 2 is a side view of a single rod;

12 FIG. 3 is a two dimensional arrangement of rods sharing
13 common electrodes;

14 FIG. 4 is a two dimensional arrangement of rods having
15 independent electrodes that can form an array of transducer
16 elements; and

17 FIG. 5 is a diagram showing layered deposition of the
18 elements used to make this invention.

19
20 DESCRIPTION OF THE PREFERRED EMBODIMENT

21 FIG. 1 shows the top view of a single co-fired piezoceramic
22 pillar 10, in this case a rod of square cross-section. A cross-
23 sectional view of this pillar 10, taken along section line A-A,
24 is shown in FIG. 1A. This is shown configured for placement in a
25 1-3 piezoelectric ceramic polymer composite substrate. As shown,

1 the structure has three active piezoelectric ceramic layers 12A,
2 12B, and 12C with four conductive electrodes 14A, 14B, 14C and
3 14D addressing the three piezoelectric ceramic layers 12A, 12B,
4 and 12C. Piezoelectric ceramic layers 12A, 12B, and 12C can be
5 constructed from typical ferroelectric materials such as lead
6 zirconate titanate or lead titanate. A top electrode 14A is
7 positioned on the upper surface of pillar 10. Top electrode 14A
8 is in communication with lower intermediate electrode 14C via
9 first trace 16A. A bottom electrode 14D is positioned on the
10 bottom surface of pillar 10.

11 Pillar 10 is polarized so that an electrode having a
12 positive polarity is in contact with a positively polarized
13 portion of pillar 10. For example, if top electrode 14A is
14 positive then the top surface of ceramic layer 12A is positively
15 polarized, and the bottom surface of ceramic layer 12A is
16 negatively polarized where it is in contact with top intermediate
17 electrode 14B. The bottom electrode 14D would then have a
18 negative polarity. Ceramic layer 12C bottom surface is
19 negatively polarized where it contacts bottom electrode 14D.
20 Ceramic layer 12C top surface is positively polarized where it
21 contacts lower intermediate electrode 14C because electrode 14C
22 has a positive polarity. Intermediate ceramic layer 12B has a
23 top surface that is negatively polarized and in contact with
24 upper intermediate electrode 14B. Bottom surface of ceramic
25 layer 12B is positively polarized and in contact with electrode

1 14C. Thus, polarized ceramic regions should be in contact with
2 electrodes having a like polarization.

3 FIG. 2 provides a side view of pillar 10 showing top
4 electrode 14A, trace 16A and bottom electrode 14D. Bottom
5 electrode 14D is in communication with upper intermediate
6 electrode 14B via second trace 16B. An electrical insulator
7 material 18 is used to isolate traces 16A and 16B from the pillar
8 10. Electrical insulation between the traces and the pillar 10
9 prevents leakage of currents across the individual ceramic
10 layers. Thus, top electrode 14A and lower intermediate electrode
11 14C can be associated with one electrical pole, and bottom
12 electrode 14D and upper intermediate electrode 14B can be
13 associated with the other electrical pole. Electrodes 14A, 14B,
14 14C, and 14D and traces 16A and 16B can be made from any
15 electrically conductive material. It is envisioned that top
16 electrode 14A and bottom electrode 14D are formed from continuous
17 depositions of conductive material so that one top electrode or
18 bottom electrode can contact a multiplicity of ceramic layers 12A
19 and 12C, and a multiplicity of traces 16A and 16B respectively
20 forming a multiplicity of co-fired assemblies.

21 As arranged above, top electrode 14A and upper intermediate
22 electrode 14B are in electrical contact with active ceramic layer
23 12A. In a passive mode, compression of active ceramic layer 12A
24 results in generation of a differential voltage between electrode
25 14A and electrode 14B. In an active mode, application of a

1 differential voltage across ceramic layer 12A results in movement
2 of this layer. In the same manner, active ceramic layer 12B is
3 joined for communication with electrodes 14B and 14C, and active
4 ceramic layer 12C is joined for communication with electrodes 14C
5 and 14D. Because more electrodes are provided, a lower voltage
6 applied between 14A and 14D can give the same displacement of
7 pillar 10.

8 FIG. 3 shows a panel 20 having a plurality of pillars 10
9 arranged over a planar surface. Pillars 10 are supported in
10 panel 20 by insulating material 18. Insulating material 18 can
11 be a dielectric polymer matrix or an elastomeric material. In
12 this embodiment, top and bottom electrodes 14A and 14D are
13 extended over the upper and lower surfaces of the entire panel
14 20. A plurality of first traces 16A make contact with top
15 electrode 14A, and a plurality of second traces 16B make contact
16 with bottom electrode 14D. As above, each first trace 16A is in
17 contact with one lower intermediate electrode 14C. Each second
18 trace 16B is in contact with one upper intermediate electrode
19 14B. While the panel shown here has two traces 16A and 16B for
20 each pillar 10, it is understood that each trace 16A and 16B can
21 be in communication with multiple electrodes in multiple pillars
22 10. In FIG. 3, pillars 10 are shown arranged in offset rows;
23 however, other patterns of arrangement are possible for efficient
24 utilization of the space.

1 An alternative embodiment of the invention is shown in FIG.
2 4. Panel 20' has a top electrode 22A and a bottom electrode 22B
3 associated with each pillar 10. As above, top electrode 22A is
4 joined to a first trace 16A which electrically connects top
5 electrode 22A with one lower intermediate electrode 14C. Bottom
6 electrode 22B is electrically joined to upper intermediate
7 electrode 14B via second trace 16B. This arrangement allows
8 independent addressing of the pillars 10. In view of these two
9 embodiments any number of groups of pillars can be independently
10 addressed.

11 Panels 20 and 20' can be manufactured by the fused
12 deposition of ceramics (FDC) method as shown in FIG. 5.
13 Utilizing this method hundreds of columns can be generated in two
14 orthogonal directions. The example shown above is a composite
15 with 1-3 connectivity (rods in two directions), but the method
16 could also be used to fashion a composite with 2-2 connectivity
17 (plates in one direction).

18 The FDC method utilizes a numerically controlled multi-
19 nozzle 30 head in communication with reservoirs 32A, 32B, 32C and
20 32D of various thixotropic materials of interest as shown in FIG.
21 4. Nozzle 30 can precisely dispense these materials over a two-
22 dimensional grid 34. Materials can include green ceramic,
23 metallic compounds, and other polymers. The build-up over
24 multiple layers is accomplished by lowering the two-dimensional
25 grid 34 and depositing layer 36 upon layer 36 to create a

1 multiple layer pre-form 38. This pre-form 38 will typically
2 include the piezoceramic layers 12A, 12B and 12C; the
3 intermediate electrodes 14B and 14C; insulating material 18 and
4 the traces 16A and 16B for a plurality of pillars 10.

5 Once deposition of the pre-form 38 is complete the pre-form
6 38 is subjected to a low temperature burn out to remove the
7 plasticizer in the sprayed material. Pre-form 38 is then fired
8 to sinter the ceramic particles. The pre-form 38 may be back-
9 filled with a polymer to hold the pillars together while
10 mechanically decoupling the piezoceramic pillars 10 from each
11 other. This can be the same insulating material as insulating
12 material 18 or a different insulating material. The top and
13 bottom electrodes 14A and 14D can be applied to the outside
14 of the finished composite substrate. The pillars 10 are
15 polarized by a number of methods dependent upon the piezoelectric
16 material utilized.

17 An alternative approach, quasi-multi-layering, involves
18 applying conductive stripes around the pillars. This is similar
19 to conventional striped ceramic cylinders. The realization of
20 this method would be complicated and perhaps not as cost
21 effective as the disclosed method. Additionally, the field
22 impressed on the surface doesn't couple completely to the
23 internal volume of the active material.

1 In view of the above detailed description, it is anticipated
2 that the invention herein will have far reaching applications
3 other than those described herein.

4 This invention has been disclosed in terms of certain
5 embodiments. It will be apparent that many modifications can be
6 made to the disclosed apparatus without departing from the
7 invention. Therefore, it is the intent of the appended claims to
8 cover all such variations and modifications as come within the
9 true spirit and scope of this invention.

6 A piezoelectric ceramic polymer composite is provided with
7 piezoelectric ceramic pillars having intermediate electrodes.
8 These intermediate electrodes reduce the voltage necessary to
9 achieve a given polarizing electric field within the
10 piezoelectric ceramic pillars. Upper and lower electrodes are
11 provided on the surfaces of the composite substrate. These
12 electrodes are electrically joined to the intermediate electrodes
13 by insulated electrical traces. The piezoelectric ceramic phase
14 geometry may include either 1-3 (rods) or 2-2 (bars)
15 connectivity. The number of electrode pairs is limited only by
16 the fabrication process. The lateral distribution of these
17 piezoelectric pillars is decoupled using a polymer backfill
18 material. Upper and lower electrodes can be partitioned to form
19 an array of transducer elements.

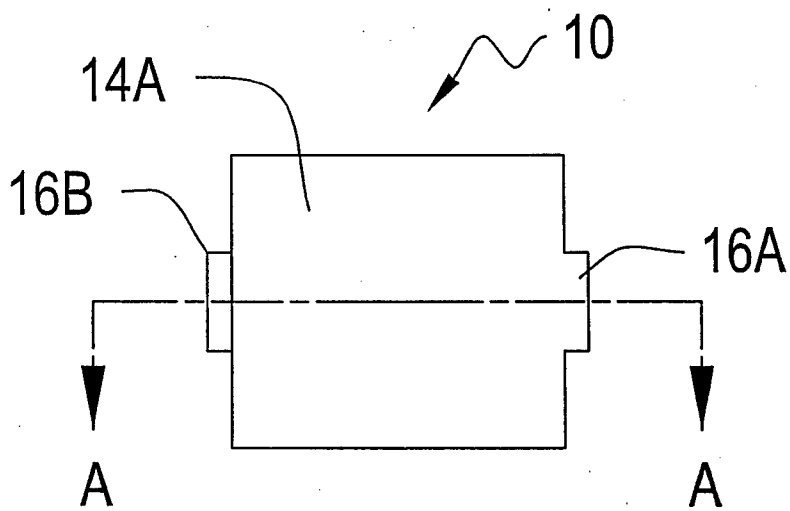


FIG. 1

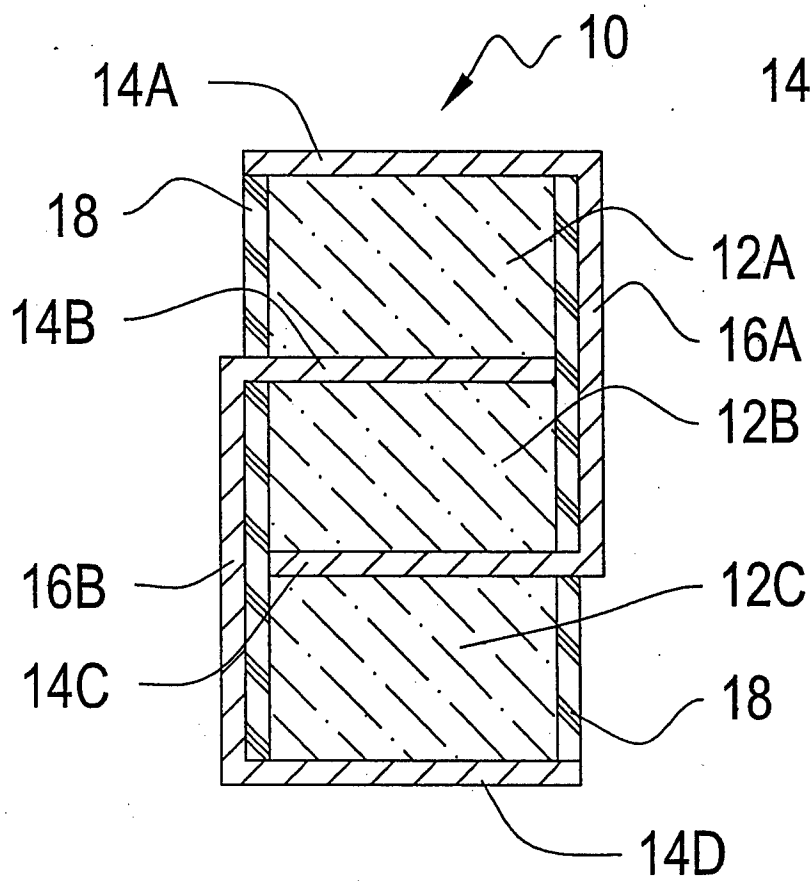


FIG. 1A

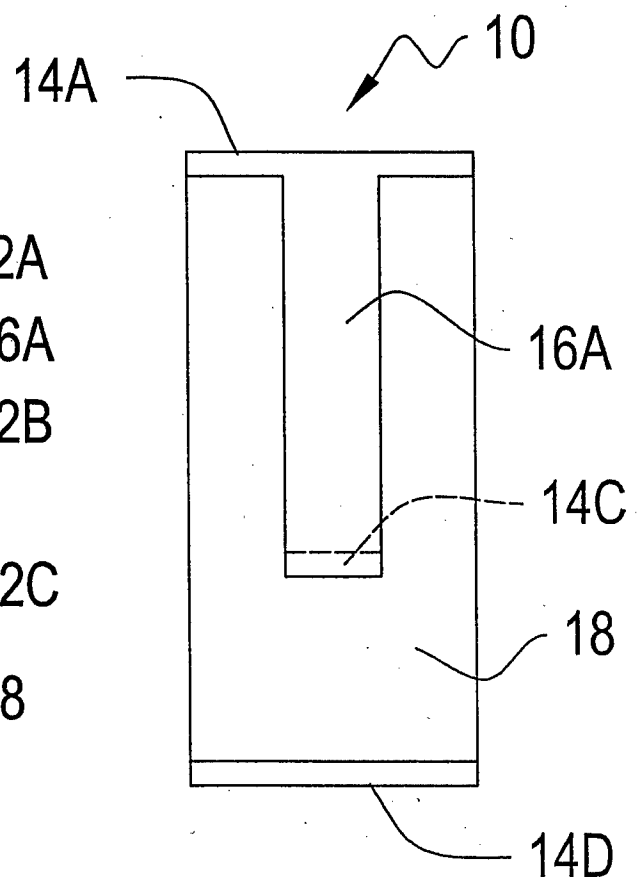


FIG. 2

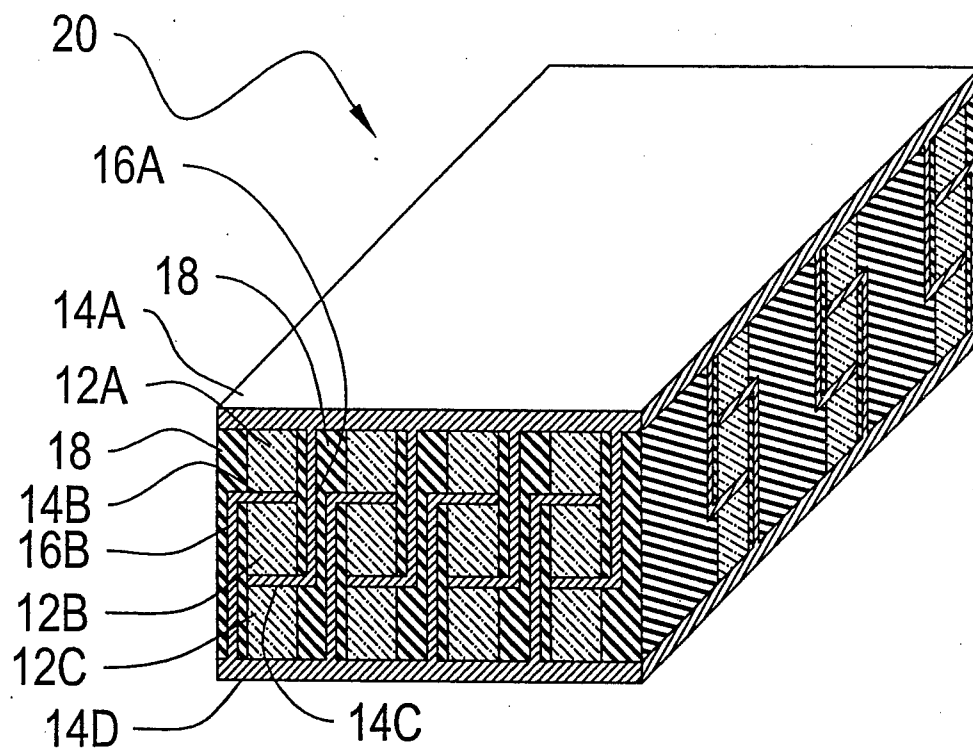


FIG. 3

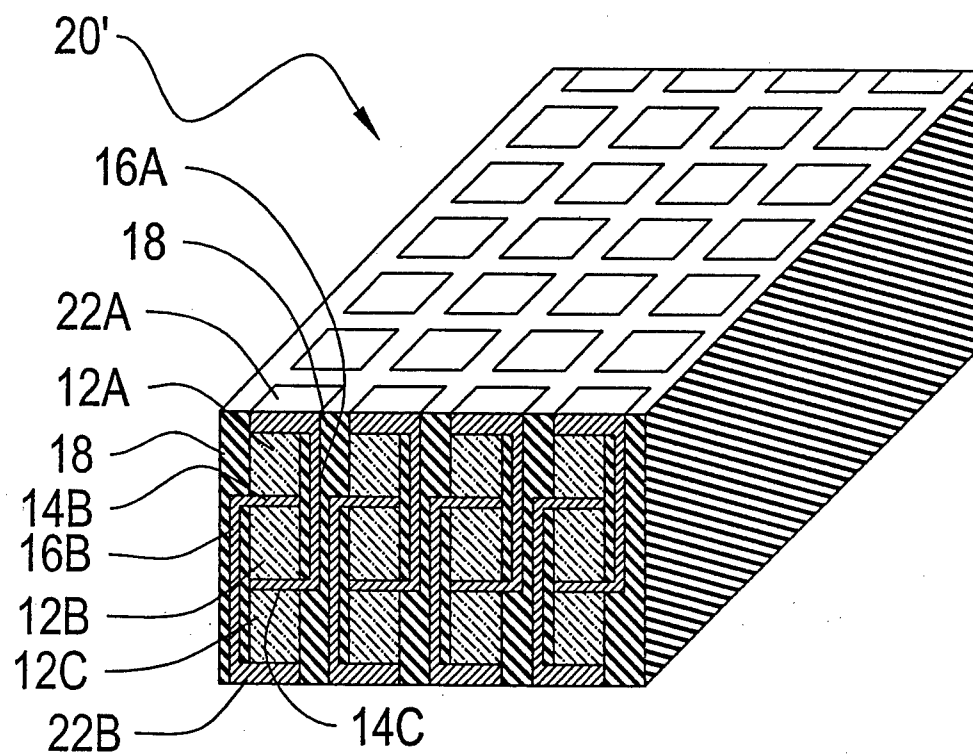


FIG. 4

